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Density of Statically Deposited Bed

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ABSTRACT

Variation of density for statically deposited cohesive sediment bed was investigated under the effect of salinity and consolidation period. The density of natural mud and kaolinite bed was found to increase with depth. This was due to the variation in initial suspension concentration and overburden. Salinity is found to have little effect on bed density, while consolidation causes the bed density to increase with depth. Overall density for kaolinite is higher than natural mud. The density profile for seven test beds is nearly S shape.

ABSTRAK

Satu kajian ketumpatan untuk lapisan dasar endapan jeleket di bawah pengaruh kemasinan dan masa pemampatan telah dilakukan. Ketumpatan lapisan dasar lumpur asli dan lapisan kaolinit didapati adalah meningkat dengan kedalaman. Ini adalah disebabkan oleh perubahan di dalam kepekatan apungan awal dan beban yang dikenakan. Kemasinan didapati mempunyai kesan yang sedikit ke atas ketumpatan lapisan dasar, sementara pemampatan menyebabkan peningkatan ketumpatan lapisan dasar berbanding kedalaman lapisan. Ketumpatan keseluruhan untuk kaolinit adalah lebih tinggi berbanding lumpur asli. Profil ketumpatan untuk tujuh ujikaji yang dilakukan mempunyai bentuk menyerupai huruf S.

INTRODUCTION

Estuarial sediments are mostly clayey particles deposited under repeated cycles of tidal action. Normally, fine particles have a settling diameter of less than 5 μm and a large specific area which enhance the surfacial physico-chemical forces. In saline environment, these forces become attractive and cause the clay particles to stick together to form flocs. At slack water period, these flocs are deposited in estuarine zone. The size and settling velocities of these flocs depend on flow conditions in estuary.

Surfacial layers of estuarial beds are deposited in three different states: stationary suspensions, partially consolidated beds and settled beds (Hayter 1984). The top few centimeters of stationary suspensions tend to have low bulk density and high water content. Bulk density for stationary suspensions is approximately 1050 kg/m^3 (Parker & Kirby 1977). With time dependent consolidation, stationary suspensions are tranformed into partially consolidated beds having a lower water content and higher density. Further consolidation caused the formation of settled beds with much lower water content and a higher density. The density for settled beds varies from 1300 to 1700 kg/m^3 (Parker & Kirby 1983). Mehta et. al. (Mehta & Partheniades 1982) established the mass balance equation between deposited sediment and suspended particles. This equation is able to calculate depth of scour, provided bed density is known. Deposition of fine sediments in harbors and navigational channels requires dredging operation, and prediction of dredging depth is an important aspect in cohesive sediment transport modelling.

The objective of this paper is to investigate the bed densities of soft cohesive sediments which are typically found in Malaysia estuaries. The effect of salinities and consolidation are studied. Results and expression proposed in this paper are applicable for determining bed density in any site specific investigation. Depth averaged value of density was calculated as a mean throughout the depth.

APPARATUS

Dry density of statically deposited bed was determined using an apparatus developed by Parchure (Parchure 1990). The size and diameter of polyvinyl chloride (PVC) test apparatus were modified as shown in Figure 1 to facilitate the use of thicker beds. A 16 cm diameter PVC pipe was cut into two pieces. The top part was 60 cm and the bottom part was 23 cm which was glued to the bottom on the piece of plexiglass sheet. Ten 1.8 cm diameter PVC tubes ranging in height from 2 cm to 16 cm were glued to the bottom. Each succesive tube was 2 cm different in height from adjacent one. A pipette (25 cc) was used for collecting samples from each of the PVC tube.

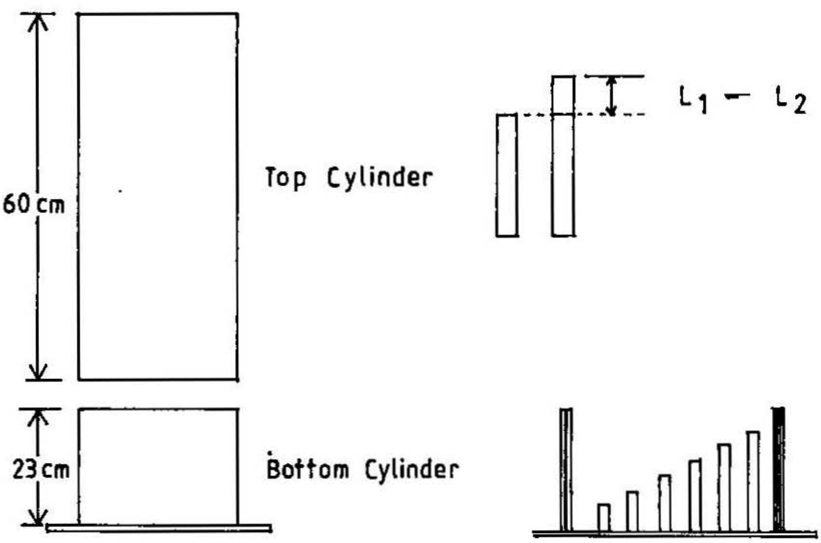

FIGURE 1. Schematic Representation of Apparatus for Measurement of Statically Deposited Bed Densities

PREPARATION OF BED

Four different Kuala Selangor (KS) mud beds and three different kaolinite beds were prepared. An adequate amount of kaolinite was submerged in 10.0 ppt saline water for one week for equilibration in between the pore and supernatant fluid. Before placing into the three separate PVC columns, kaolin-saline water mixture was further agitated by a stirrer for approximately 5 minutes. The thick slurry was then poured into the PVC columns and allowed to be deposited for 1.75, 2.75, and 5.75 days consolidation period respectively. The other four PVC columns were filled with KS mud-water mixture (after equilibration with saline water) for 1.0, 2.0, 5.0, and 10.0 ppt salt concentration. The consolidation period was 1.75 days for all four mud beds, but the initial concentrations were 52.0, 46.5, 48.2, and 56.3 gm/l.

DENSITY CALCULATION

L_1 and L_2 are heights of two adjacent tubes and ρ_1 and ρ_2 are densities of sediment in each tube. V_1 and V_2 are the volume of sediment in each tube respectively. It is assumed that the bottom portion of the sediment in tube L_1 had the same density as tube L_2. Therefore, the difference in densities ρ_1 and ρ_2 due to the differential height $(L_1 - L_2)$ was calculated as follows:

$$(\Delta\rho)_{1-2} = \frac{\rho_1 V_1 - \rho_2 V_2}{V_1 - V_2} \tag{1}$$

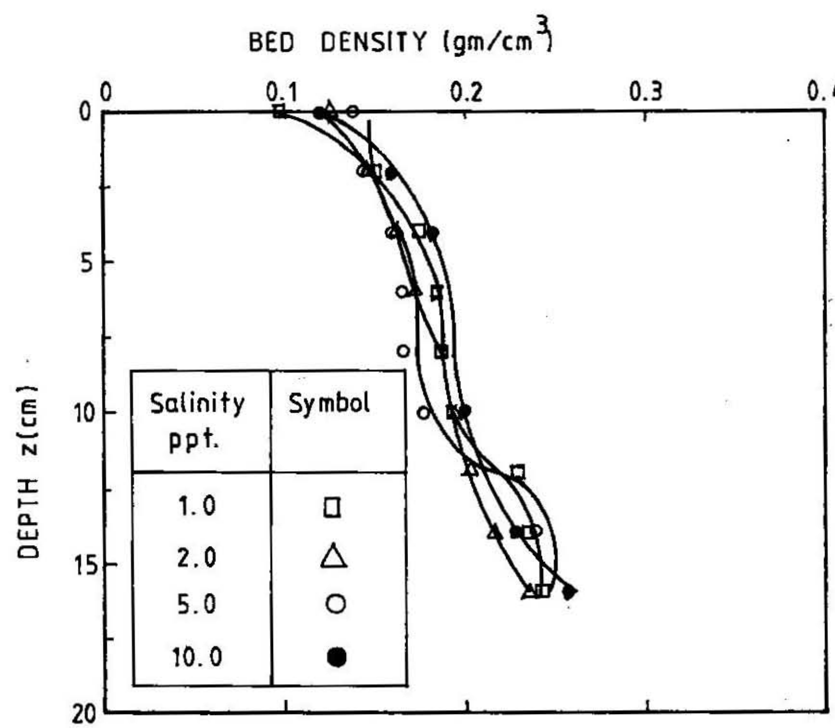

FIGURE 2. Variation of bed density as a function of depth for KS mud

RESULTS

It was found that the bed density of Kuala Selangor mud increases with depth. The density profiles are as shown in Figure 2 for mud samples at different salinity are nearly similar to S shape. It is evident from Figure 2 that the salinity has no effect on bed density for Kuala Selangor mud. The erratic displacement of the four profiles is due to different suspended sediment concentration. The minimum and maximum bed densities are 0.0981 gm/cu.cm at 1.0 ppt salinity and 0.2569 gm/cu.cm at 10 ppt salinity respectively. The effect of different salinity, namely 1.0, 2.0, 5.0, and 10.0 ppt concentration is not remarkable on the variation of depth-averaged bed density. The depth-averaged bed density $\bar{\rho}$ of Kuala Selangor mud increases with initial suspended sediment concentration C_0 as shown in Figure 3.

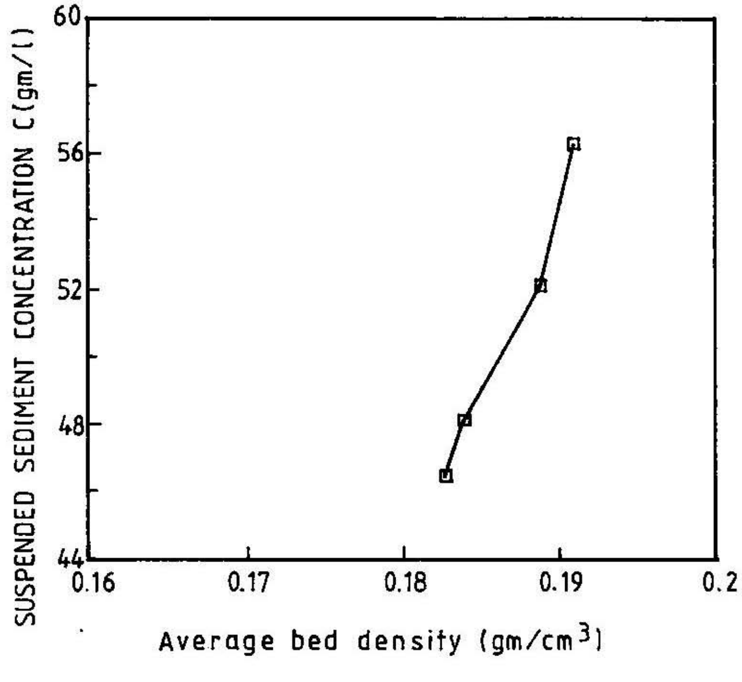

FIGURE 3. Effect of initial suspended sediment concentration on average bed density

Figure 4 shows that bed density of commercial grade kaolinite also increases with depth. The effect of consolidation on bed density is manifested in Figure 5. For 1.75, 2.75, and 5.75 days of consolidation period, surfacial bed is almost the same for three kaolinite test samples. The reason is due to the absence of overburden at the surface. At maximum depth (14.5 to 15.5 cm for the present study) the values are 0.3616, 0.4284, and 0.5363 gm/cu.cm respectively.

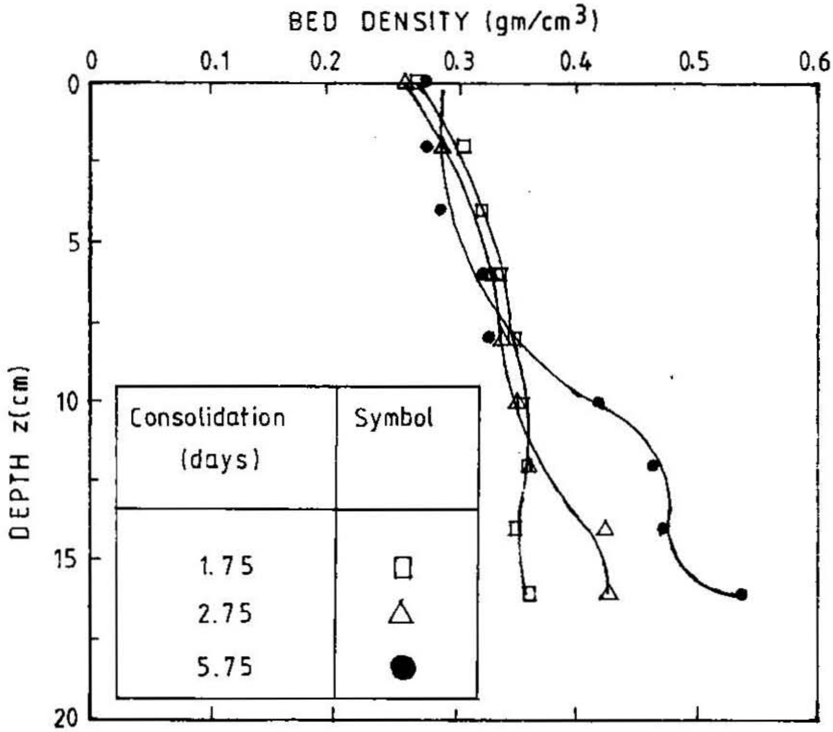

FIGURE 4. Variation of bed density as a function of depth for kaolinite

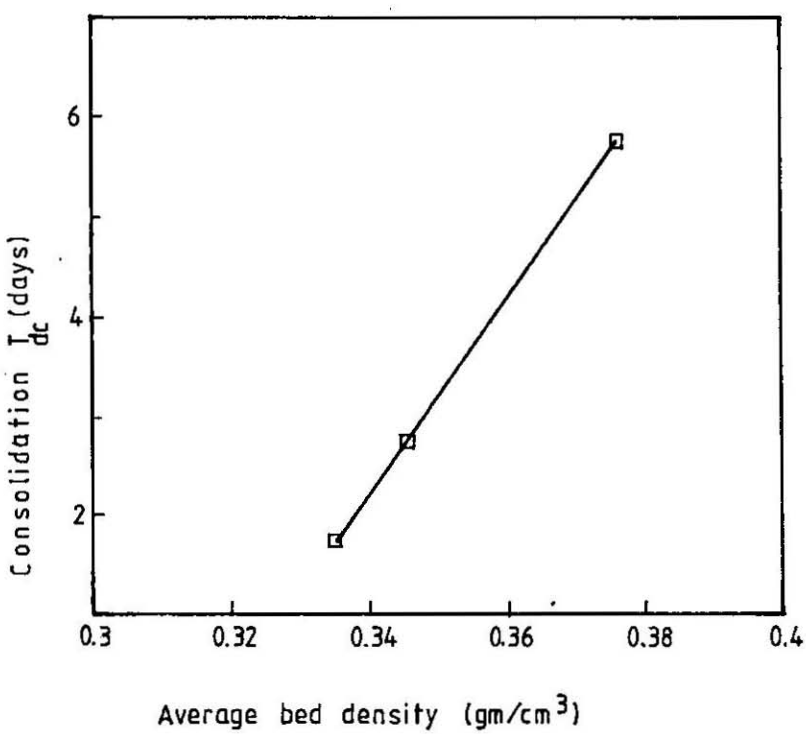

FIGURE 5. Effect of consolidation on average bed density

The depth-averaged bed density $\bar{\rho}$ for three kaolinite samples was found to increase with consolidation period. The depth-averaged bed density for kaolinite is greater than Kuala Selangor mud as shown in Figure 6 for the same salinity (10.0 ppt) and consolidation period (1.75 days).

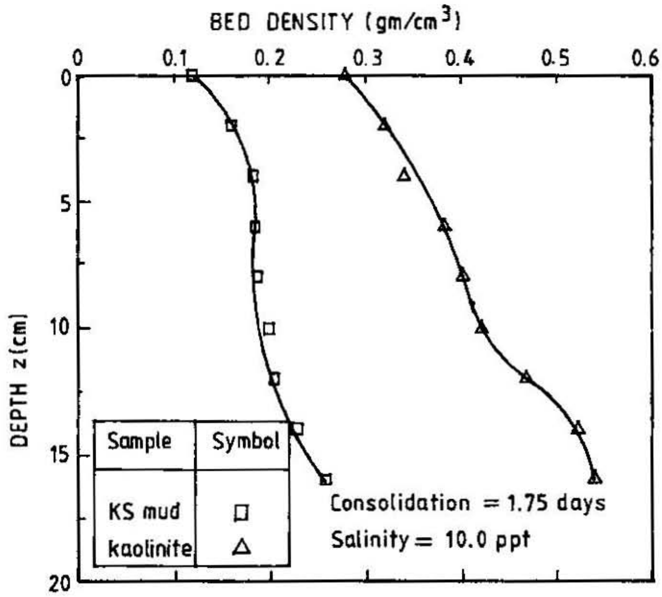

FIGURE 6. Density profiles as a function of depth for mud and kaolinite bed for the same consolidation period and salinity

To observe the variation of bed density, normalized value of the bed density $\frac{\rho}{\bar{\rho}}$ was plotted against the normalized depth, $\frac{z}{z_0}$, where z_0 is the initial bed thickness. Figure 7 and 8 represent variation of normalized bed density and normalized depth for KS mud and kaolinite bed respectively. The relationships between the normalized bed density, $\frac{\rho}{\bar{\rho}}$, and the normalized depth, $\frac{z}{z_0}$, for each series are expressed as follows:

KS mud: $$\frac{z}{z_0} = 0.5102 + 1.734 \ln\left(\frac{\rho}{\bar{\rho}}\right) \tag{2}$$

Kaolinite: $$\frac{z}{z_0} = 0.5337 + 1.558 \ln\left(\frac{\rho}{\bar{\rho}}\right) \tag{3}$$

The above relationship for KS mud is independent of salinity, while the relationship for kaolinite is independent of consolidation. Figure 9 shows individual profile for kaolinite bed at different consolidation period. For KS

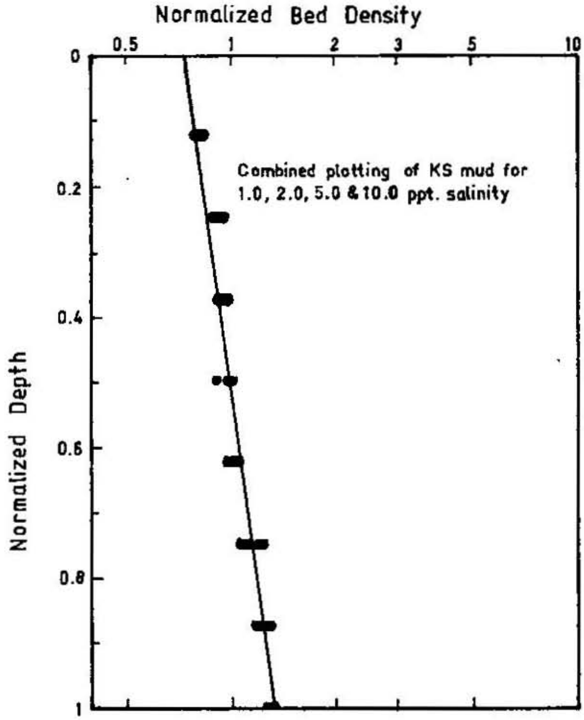

FIGURE 7. Variation of normalized bed density with normalized depth

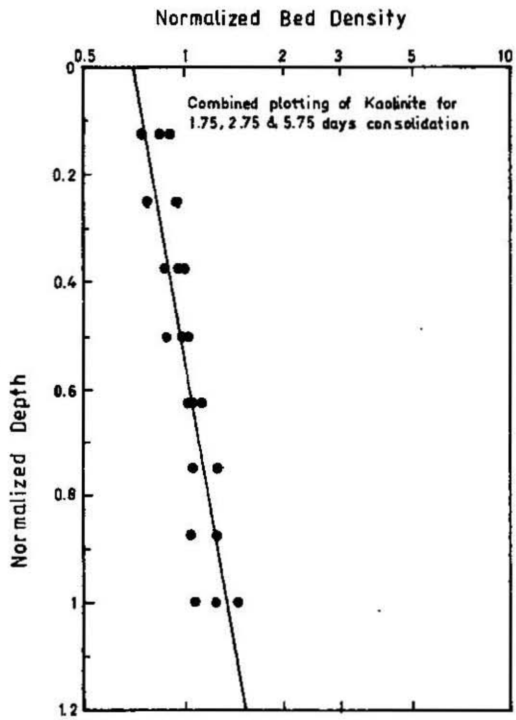

FIGURE 8. Variation of normalized bed density with normalized depth

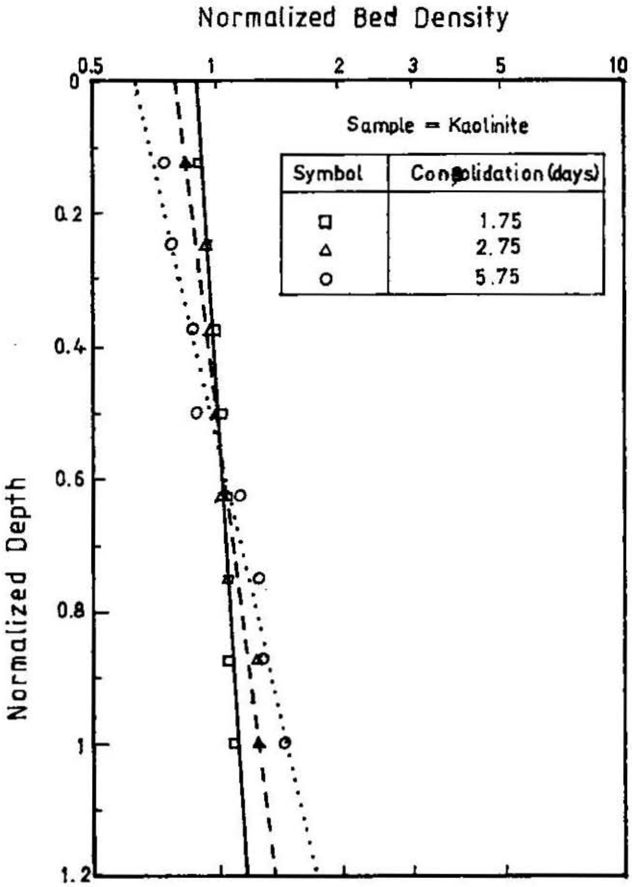

FIGURE 9. Variation of normalized bed density with normalized depth

mud, the individual profiles are identical at different salinity. Following are the relationships for three kaolinite samples:

T_{dc} *(days)*	Relationship	Equation Number
1.75 :	$\frac{z}{z_0} = 0.4956 + 4.672 \ln\left(\frac{\rho}{\bar{\rho}}\right)$	(4)
2.75 :	$\frac{z}{z_0} = 0.5078 + 2.227 \ln\left(\frac{\rho}{\bar{\rho}}\right)$	(5)
5.75 :	$\frac{z}{z_0} = 0.5427 + 1.209 \ln\left(\frac{\rho}{\bar{\rho}}\right)$	(6)

A general relationship can be considered for all the KS mud and kaolinite samples. The expression is as follows:

$$\frac{z}{z_0} = \alpha + \beta \ln\left(\frac{\rho}{\bar{\rho}}\right) \tag{7}$$

The range of $\frac{\rho}{\bar{\rho}}$ throughout the depth for KS mud and kaolinite is given in Table 1.

TABLE 1. Values of $\frac{\rho}{\bar{\rho}}$ at different depth

	KS mud	Kaolinite
Surface	0.51	0.53
Mid-depth	1.0	1.0
Bottom	1.2	1.40

Following are observations from the density profile:

1. The relationship between the normalized bed density, $\frac{\rho}{\bar{\rho}}$ and normalized depth, $\frac{z}{z_0}$ is logarithmic
2. All the data points for the KS mud attribute to less dependency on salinity variation. For kaolinite, points are scattered due to variation in consolidation.
3. The relationship between the normalized bed density and normalized depth shown in Figure 9 for the three kaolinite samples is almost the same except for some variation in the coefficient β i.e. the slope of the line. This variation is due to the change in consolidation period which is evident in Figure 10. A power regression analysis in the log-log paper yielded a relationship between the coefficient β and the consolidation period T_{dc} , which is given as follows:

$$\beta = \frac{7.94}{T_{dc}^{1.11}} \tag{8}$$

4) Table 1 shows that $\frac{\rho}{\bar{\rho}}$ values at mid-depth of KS mud and kaolinite are the same. At surfacial level $\frac{\rho}{\bar{\rho}}$ (kaolinite) is a bit higher than $\frac{\rho}{\bar{\rho}}$ (KS mud). However at the bottom, the difference is remarkable. This greater difference at the bottom may be due to the greater density in kaolinite compared to that of KS mud.

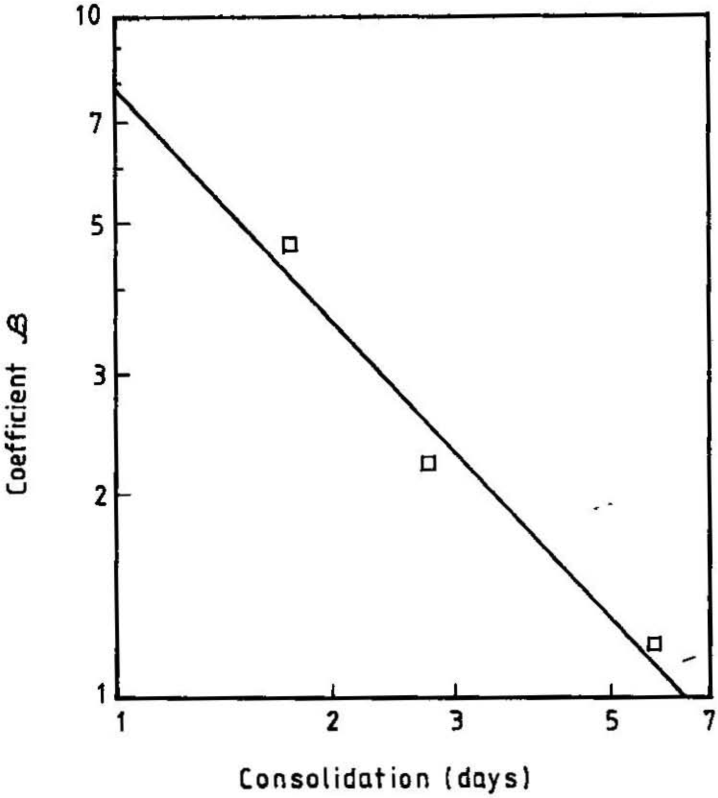

FIGURE 10. Relationship between the consolidation period and the coefficient β

DISCUSSION

During the deposition of suspended sediment, a particular layer experiences an exerted pressure or crush by the overlying layers. Overburden increases with number of overlying layers. This trend causes a greater compaction at lower depth, which results in stratified bed density pattern. Increase of bed density with depth is also due to the lower order of aggregation in the soft cohesive sediment deposit. Lower order aggregates are usually smaller in size and closer particle arrangement compared to those of higher order aggregates with larger sizes and looser particle grouping.

Although the influence of initial concentration was not well understood, it may be possible that at lower initial concentration, the particle's contact is edge to face and at higher value, the contact is face to face. The face to face contact of clay particles causes close arrangement, hence a higher bed density compared to the edge to face contact.

Equation 2 can be used to determine bed density. Empirical coefficient α and β are consolidation dependent. Coefficient β is varied from 0 to ∞ while α is increased with consolidation period. For a bed with total thickness z, the density ρ at any depth z_0 can be calculated provided $\bar{\rho}$ is known. For calculating $\bar{\rho}$, Hayter (Hayter 1984) proposed the following equation:

$$\bar{\rho} = \bar{\rho}_{T}\left[1-\theta \exp(-\lambda \frac{T_{dc}}{T_{dc_T}})\right] \tag{9}$$

where, $\bar{\rho}_T$ = mean bed density at total consolidated state, T_{dc_T}.

Empirical coefficient θ and λ are found by least square analysis.

TABLE 2. Comparison of results with previous studies

Sample		$\frac{\rho}{\bar{\rho}}$ at mid-depth	
Natural mud	0.51 (present study)	0.38 (Parchure 1984)	0.66 (Owen 1975)
Kaolinite	0.53 (present study)	0.53 (Parchure 1984)	

For kaolinite, the $\frac{\rho}{\bar{\rho}}$ value was exactly the same with the previous value as shown in Table 2. For natural mud, the slight variation was due to the differences in mud composition i.e. in respect of clay mineral content and particle size.

CONCLUSIONS

Initial suspension concentration, overburden, and lower order aggregation are principal reasons in increasing the depthwise bed density. Salinity has little effect on bed density of cohesive sediment deposit. Consolidation influences variation of density with depth. Equation 2 is applicable for determining bed density provided $\bar{\rho}$, α, and β are known.

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NOTATIONS

α = empirical coefficient
β = empirical coefficient
C_0 = initial suspended sediment concentration
λ = empirical coefficient
θ = empirical coefficient
$\bar{\rho}$ = depth averaged bed density

$\bar{\rho}_T$ = mean bed density at total consolidated state
T_{dc} = consolidation period
T_{dc_T} = total consolidated state

REFERENCES

Hayter E.J. 1984. Estuarine Bed Model, *Estuarine Cohesive Sediment Dynamics, A.J. Mehta, ed.* 14, *Springer - Verlag, Berlin, FRG.*

Parker W.R. & R. Kirby. 1977. Fine Sediment Studies Relevant to Dredging Practice and Control. *Proceedings of the Second International Symposium on Dredging Technology,* BHRA Paper b-2, *Texas A & M University, College Station, Texas.*

Parker W.R. & R. Kirby, 1983, Distribution and Behavior of Fine Sediment in the Seven Estuary and Inner Bristol Channel, *U.K. Canadian Journal of Fisheries and Aquatic Sciences* 40 *Supplement Number* 1: 83 - 95.

Parchure T.M. 1990. Effect of Bed Shear Stress on the Depositional Characteristics of Kaolinite, *Thesis presented to the University of Florida, Gainesville, U.S.A., in partial fulfillment of the requirements for the degree of Master of Science.*

Mehta, A.J. & Partheniades, E. 1982. Resuspension of Deposited Cohesive Sediment Beds, *Proceedings of 18th Coastal Engineering Conference, ASCE,* II *Cape Town, South Africa, November:* 1569 - 1588.

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